Validation of the EarthCARE mission

Rob Koopman, Alain Lefebvre, Damien Maeusli, Tobias Wehr, Michael Eisinger, Montserrat Piñol Solé (all authors are from European Space Agency)

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Preamble

Due to the transition from the workshop to an online session, the following adaptations have been made to this contribution:

• It is presented as a set of slides, in stead of the poster format mentioned in the abstract
• Verbosity is enhanced, to compensate for the absence of oral explanation
• Hyperlinks are used extensively, considering that this presentation will be viewed on a computer rather than projected on a screen
• The scope has slightly been broadened compared to the original abstract, by including a mission and product summary, in order to partially compensate for the cancellation of the mission presentation
Presentation structure

1. The EarthCARE Mission
2. The EarthCARE Data Products
3. The Joint ESA-JAXA Validation Plan
4. Validation of the ESA Data Products
5. Validation Timeline
1.1 The EarthCARE Mission: Objectives

**Earth Clouds, Aerosols, and Radiation Explorer**

EarthCARE is a joint ESA-JAXA mission that aims at understanding of cloud-aerosol interactions and radiation balance.

The scientific objectives of the mission are:

- To observe vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds
- To observe vertical distributions of atmospheric liquid water and ice on a global scale, their transport by clouds and their radiative impact
- To observe cloud distribution, cloud-precipitation interactions and the characteristics of vertical motions within clouds
- To retrieve profiles of atmospheric radiative heating and cooling through the combination of the retrieved aerosol and cloud properties
**Orbit:**
- 393 km mean altitude
- Sun Synchronous frozen orbit
- 97° Inclination
- 14h00 DSN MLST
- 25-days repeat cycle

**Lifetime:**
- 3 years + 1 (incl. 6-months commissioning)

**Space Links:**
- S-Band:
  - Kiruna KIR1 / KIR2 Ground stations
  - 64 kbps uplink
  - 128 kbps / 2 Mbps downlink (with/without ranging)
- X-Band:
  - Kiruna-Esranges & Inuvik Ground stations
  - 150 Mbps downlink

**Satellite:**
- 2350 kg (incl. 313 kg propellant)
- 3-axis stabilized / yaw-steering
- 1700W
- On-board data rates average:
  - <15 kbps (HKTM)
  - <2.5 Mbps (science)

**Payload:**
- 2 active instruments (ATLID & CPR)
- 2 passive instruments (BBR & MSI)
1.2 The EarthCARE Mission: Payload
1.3 The EarthCARE Mission: Payload

Active Instruments

ATLID: ATmospheric LIDar
- Backscatter UV lidar (355 nm) with high spectral resolution receiver, bistatic design
- 3 receiver channels: molecular, co-polar and cross-polar particle backscatter → backscatter and extinction measured independently
- Pulse repetition frequency 51 Hz, pulse energy >34 mJ
- Sampling: 290 m (=2x145 m integrated) horizontal, 103m vertical
- Receiver footprint on ground <30m
- 3 degree off-nadir (backwards) pointing to reduce specular reflection on ice clouds
- Level 1 product: attenuated backscatter profiles

CPR: Cloud Profiling Radar (JAXA/NICT)
- High power W-band (94 GHz) nadir-pointing
- Doppler capability (accuracy 1m/s)
- Antenna aperture 2.5 m
- Variable pulse repetition frequency: 6100-7500 Hz
- Sensitivity at least -35 dBZ at 20 km height
- Sampling: 500 m horizontal, 100 m vertical
- Beam footprint on ground <700 m
- Level 1 product: reflectivity & Doppler profiles

Passive Instruments

MSI: Multi-Spectral Imager
- Nadir-viewing push-broom imager
- 4 solar channels: 670 nm, 865 nm, 1.65 µm, 2.21 µm
- 3 thermal infrared channels: 8.8 µm, 10.8 µm, 12.0 µm
- 150 km swath tilted away from sunglint
- Sampling 500 m x 500 m
- Level 1 product: radiances (solar), brightness temperatures (thermal IR)

BBR: Broad-Band Radiometer
- 2 channels: total-wave 0.25-50 µm, short-wave (solar) 0.25-4 µm
- 3 fixed telescopes: nadir, forward (+50 deg), backward (-50 deg)
- Integrated pixel size of 10 km x 10 km
- Radiometric accuracy: SW 2.5 W/m2sr, LW 1.5 W/m2sr
- Level 1 product: solar and thermal TOA radiances
1.4 The EarthCARE Mission: Information

Detailed information on the EarthCARE mission is available at:

- The ESA EarthCARE website at https://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/EarthCARE
- The ESA Earthnet portal at https://earth.esa.int/web/guest/missions/esa-future-missions/earthcare
- The EarthCARE site at the EOportal https://directory.eoportal.org/web/eoportal/satellite-missions/e/earthcare
- The JAXA EarthCARE website at https://global.jaxa.jp/projects/sat/earthcare/

Please also consult:

- A scientific paper about the EarthCARE Mission in the Bulletin of the American Meteorological Society
2.1 EarthCARE Data Products: Context

- **Needs**
  - Convective updraft and ice fall speed
  - Vertical profiles of liquid, supercooled and ice water, cloud overlap, particle size and extinction
  - Cloud top and base height
  - Quantitative precipitation measurements
  - Ice water content
  - Vertical profiles of extinction and characteristics of aerosols
  - Cloud top height
  - Occurrence of layer of super cooled cloud
  - Horizontal structure of clouds and aerosols
  - Cloud type
  - Ice/water discrimination
  - Cloud and aerosol optical depth
  - Cloud top temperature
  - Cloud droplet radius
  - Cloud cover fraction
  - Cloud effective emissivity
  - Shortwave and longwave fluxes at top of the atmosphere

- **Techniques**
  - Doppler Radar
  - Radar
  - High spectral resolution Lidar
  - Multispectral Imager
  - Broadband Radiometer

- **Instruments**
  - CPR
  - ATLID
  - MSI
  - BBR

- **Geophysical Products**
  - Precipitation
  - Ice and water clouds
  - Aerosols
  - TOA Flux
2.2 EarthCARE Data Products: Sampling
2.3 EarthCARE Data Products: Parameters

- **ATLID Level 1b**: Attenuated backscatter in Rayleigh channel, co- and cross-polar Mie channels
- **ATLID Level 2a**: Feature mask, target classification, extinction, backscatter and depol. profiles, aerosol properties, ice cloud properties
- **CPR Level 1b**: Radar reflectivity profile, Doppler velocity profile
- **CPR Level 2a**: Radar reflectivity, Doppler velocity, feature mask, cloud type, liquid and ice cloud properties, vertical motion, rain and snow estimates
- **MSI Level 1b/1c**: TOA radiances for 4 solar channels, TOA brightness temperatures for 3 thermal channels
- **MSI Level 2a**: Cloud mask, liquid and ice cloud properties, cloud top height, aerosol properties
- **BBR Level 1b**: Filtered TOA total-wave and long-wave radiances
- **BBR Level 2b**: Unfiltered TOA reflected solar (short-wave) and emitted thermal (long-wave) radiances and fluxes

**2 and 3 Sensor Synergy Level 2b**: Synergistic target classification, cloud, aerosol and precipitation properties synergistically retrieved from ATLID, CPR and MSI

**Radiative Products Level 2b**: Radiative properties (heating rates, fluxes, radiances) modelled from constructed 3-dimensional cloud-aerosol scenes

**Assessment**: Comparison of modelled fluxes and radiances to BBR observations
2.4 EarthCARE ESA Data Products: Production Model

Readable version can be downloaded from: http://earth.esa.int/aos/EarthCARE ECalVal

“production model for (ESA) EarthCARE science data products”

NB. The JAXA products mentioned here are only those needed for the generation of ESA products. JAXA has its own production model

Also available at the same URL:
- ESA Product list
- JAXA Product list
- ESA ATBDs
- Validation Requirements
3.1 Validation: Definition / Scope of presentation

CEOS Definitions:
- **Calibration**: the process of quantitatively defining the system response to known controlled signal inputs.
- **Validation**: the process of assessing by independent means the quality of the data products derived from those system outputs.

Other:
- **Commissioning**: the process of assuring that all systems are tested and operated according to the mission requirements.
- **Characterisation**: the process of probing the properties of a system as a function of expected operating conditions (e.g. non-linearity, degradation, etc.). A prerequisite for most calibrations.
- **Verification**: the process of assessing whether a system or product meets is specification (IEEE)

This presentation only addresses **Validation**
3.2 Validation: Context
3.3 ESA-JAXA Validation: Roles

In scope of the EarthCARE inter-Agency cooperation, ESA and JAXA have agreed that:

• within the commissioning of the EarthCARE spacecraft, JAXA will perform the commissioning of the JAXA Cloud Profiling Radar (CPR) instrument, including a validation plan to be defined by JAXA under the ESA-JAXA collaboration.
• ESA will integrate the JAXA-defined CPR validation plan into the overall EarthCARE validation plan.

Each Agency is responsible for the validation of its own EarthCARE data products.

The ESA-JAXA collaboration is laid down in the joint EarthCARE Scientific Validation Implementation Plan that is being finalised at present:
3.4 ESA-JAXA Validation: Implementation Plan

This Scientific Validation Implementation Plan captures the mission validation objectives, schedule, context, and definitions, and details the activities under the auspices of each Agency for the validation of its respective data products.

Each Agency has solicited validation contributions from the scientific community:

- ESA organised an Announcement of Opportunity in 2017
- JAXA organised two Research Announcements, in 2013 and in 2019. JAXA has contracted additional support for tasks not covered by the Research Announcements

The ESA activities will be described in this presentation (item 4).

ESA and JAXA will provide their preliminary products exclusively to the Validation Scientists well before the public release of the consolidated ESA and JAXA EarthCARE data products. This is explained in the timeline on the following slide.
### 3.5 ESA-JAXA Validation: release of data products

<table>
<thead>
<tr>
<th>Launch</th>
<th>Month 1</th>
<th>LEOP</th>
<th>Functional Checkout</th>
<th>Decontamination Characterisation Calibration</th>
<th>In-Orbit Verification</th>
<th>Ground Segment Verification</th>
</tr>
</thead>
</table>

**Commissioning Phase (E1):**
- Month 2
- Month 3
- Month 4
- Month 5
- Month 6

**Evolution Phase (E2):**
- Month 7
- Month 8
- Month 9
- Month 18
- Month 36

**Phase F:**
- Month X
- Month X+n

**Algorithm Evolution**
- Delta validation data set # N
- Reprocessing # N

**Public Release of L2a and 2-sensor L2b to Validation Teams**
- Public Release of L1b

**Intention:**
- To release preliminary products to the validation scientists as soon as they are stable, with description of caveats.
4.1 Validation of the ESA EarthCARE Products

The following slides focus on the validation of the ESA Products.

ESA and JAXA solicit recommendations from Mission Advisory Groups (MAG). The Joint MAG (JMAG) advises both Agencies, The European MAG (EuroMAG) advises ESA. The EuroMAG has formulated Validation Requirements for the ESA products. In 2017, the scientific community has been requested to propose contributions to meet these validation needs.

The activities resulting from this Announcement of Opportunity are summarised in this fourth part of the presentation.
4.2 Validation Activities for the ESA Products: PIs

A total of 33 Principal Investigators lead as many scientific teams contributing to the Validation of the ESA products. (one of the PIs leads 2 proposals)

These teams make correlative observations (see next slides) collocated with EarthCARE measurements, and perform scientific analyses of the deviations.

<table>
<thead>
<tr>
<th>Principal investigator</th>
<th>Institution</th>
<th>Principal investigator</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. Clerbaux</td>
<td>BIRA, BE</td>
<td>E. Welton</td>
<td>NASA-GSFC USA</td>
</tr>
<tr>
<td>F. Marenco</td>
<td>Met Office, UK</td>
<td>M. Gausa</td>
<td>Andoya Sp.C, NO</td>
</tr>
<tr>
<td>U. Wandinger</td>
<td>Tropos, DE</td>
<td>D. Josset</td>
<td>NRL, USA</td>
</tr>
<tr>
<td>C. Gentthon</td>
<td>CNRS, FR</td>
<td>X. Hu</td>
<td>NSMC, CN</td>
</tr>
<tr>
<td>A. Apituley</td>
<td>KNMI, NL</td>
<td>V. Chandrasekar</td>
<td>FMI, FI</td>
</tr>
<tr>
<td>N. Loeb</td>
<td>NASA-LARC, USA</td>
<td>T. Nishizawa</td>
<td>NIES, JP</td>
</tr>
<tr>
<td>E. Landulfo</td>
<td>IPEN, BR</td>
<td>V. Amiridis</td>
<td>NOA, GR</td>
</tr>
<tr>
<td>D. Moiseev</td>
<td>Un. Helsinki, FI</td>
<td>H. Chepfer</td>
<td>UPMC, FR</td>
</tr>
<tr>
<td>J-B. Renard</td>
<td>LPC2E-CNRS, FR</td>
<td>D. Donovan</td>
<td>KNMI, NL</td>
</tr>
<tr>
<td>J. Delanoe</td>
<td>LATMOS, FR</td>
<td>S. Tanelli</td>
<td>NASA-JPL, USA</td>
</tr>
<tr>
<td>G L. Liberti</td>
<td>CNR-ISAC</td>
<td>D. Perez-Ramirez</td>
<td>U. Granada, ES</td>
</tr>
<tr>
<td>M. Tesche</td>
<td>U Hertfortshire UK</td>
<td>Y. Markonis</td>
<td>U. Life Sciences, CZ</td>
</tr>
<tr>
<td>G. Ancellet</td>
<td>CNRS-LATMOS, FR</td>
<td>N. Scott</td>
<td>LMD/IPS, FR</td>
</tr>
<tr>
<td>A. Apituley</td>
<td>KNMI, NL</td>
<td>D. Winker</td>
<td>NASA-LARC, USA</td>
</tr>
<tr>
<td>Ph. Gouloub</td>
<td>CNRS/Lille, FR</td>
<td>H. Barker</td>
<td>Environment Canada</td>
</tr>
<tr>
<td>A. Devasthale</td>
<td>SMHI, SE</td>
<td>C. Hostetler</td>
<td>NASA-LARC, USA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P. Völger</td>
<td>IRF, SE</td>
</tr>
</tbody>
</table>
### 4.3 Airborne platforms and instruments contributing to EarthCARE Validation

<table>
<thead>
<tr>
<th>Platform</th>
<th>Instruments/Probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAAM</td>
<td>CTH/Aerosol LIDAR, MARSS radiometer, various in-situ</td>
</tr>
<tr>
<td>HALO</td>
<td>WALES LIDAR, Cloud radar, imager, various in-situ, Cloud radar, MWR, solar radiation,</td>
</tr>
<tr>
<td>DLR Falcon</td>
<td>in-situ cloud probes, hygrometer, dropsondes, etc.</td>
</tr>
<tr>
<td>LOAC Voltaire</td>
<td>Light Optical Particle Counter</td>
</tr>
<tr>
<td>Strateole</td>
<td>BeCOOL lidar, backscatter tethered sonde, etc.</td>
</tr>
<tr>
<td>ATR42</td>
<td>RASTA and BASTA radars, LNG Lidar (355nm), ALIAS LIDAR (355nm) Radiometers etc.</td>
</tr>
<tr>
<td>STRATOBUS</td>
<td>BASTA</td>
</tr>
<tr>
<td>Polar 6</td>
<td>in-situ probes, MIRAC RADAR (95), AMALI LIDAR (355nm)</td>
</tr>
<tr>
<td>Vulcanair (TBC)</td>
<td>Nd-YAG system at 532 (TBC)</td>
</tr>
<tr>
<td>TBC</td>
<td>355 lidar (CNES – Russia collaboration) (TBC)</td>
</tr>
<tr>
<td>Norwegian Aircraft</td>
<td>Nezerov probe (LWC, TWC)</td>
</tr>
<tr>
<td>NASA LaRC Aircraft</td>
<td>HSR Lidar</td>
</tr>
<tr>
<td>NASA JPL Aircraft</td>
<td>Precipitation and Cloud Radar</td>
</tr>
<tr>
<td>EUFAR (TBC)</td>
<td>Various Lidars (TBC)</td>
</tr>
<tr>
<td>Canadian Convair</td>
<td>94GHz cloud radar, (355nm) backscatter Lidar</td>
</tr>
<tr>
<td>various UAVs</td>
<td>Various instruments, including WALI Lidar, etc.</td>
</tr>
</tbody>
</table>
### 4.4 Pre-Launch Airborne Campaigns for EarthCARE

<table>
<thead>
<tr>
<th>Campaign</th>
<th>Location</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>NARPEX EPATAN</td>
<td>North Atlantic</td>
<td>2016</td>
</tr>
<tr>
<td>A-CARE</td>
<td>Mediterranean</td>
<td>2017</td>
</tr>
<tr>
<td>Tropical Campaign</td>
<td>Cape Verde</td>
<td>2021</td>
</tr>
</tbody>
</table>
4.5 Ground-based instrumentation contributing to ESA EarthCARE validation

<table>
<thead>
<tr>
<th>instrument</th>
<th>instrument</th>
<th>instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Multiwavelength) Raman- (polarisation) Lidar</td>
<td>(Profiling) Cloud radar</td>
<td>(Microwave)/(visible) radiometer</td>
</tr>
<tr>
<td>Backscatter Lidar</td>
<td>Ceilometer</td>
<td>radiosonde</td>
</tr>
<tr>
<td>Doppler Lidar</td>
<td>(micro) rain radar (profiler)</td>
<td>Pyrometer</td>
</tr>
<tr>
<td>(multi channel) (multi-wavelength) RMR Lidar</td>
<td>Precipitation radar</td>
<td>Pyranometers and Pyrgeometers</td>
</tr>
<tr>
<td>Aerosol Lidar</td>
<td>Radar wind profiler</td>
<td>Optical distrometer</td>
</tr>
<tr>
<td>Micro-Pulse Lidar</td>
<td>Weather radar</td>
<td>Sun sky radiometer</td>
</tr>
<tr>
<td>Nephelometer</td>
<td>Aethalometer</td>
<td>Sun photometer</td>
</tr>
<tr>
<td>(Pandora)(Precision) spectrometer</td>
<td>(Optical) Particle (Counter)/(Sampler)</td>
<td></td>
</tr>
</tbody>
</table>
4.6 Ground-based sites involved in EarthCARE Validation

(lidars and radars. Dense networks and other instrument types are not shown)
### 4.7 Satellite intercomparisons for EarthCARE Validation

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR</td>
<td>GERB</td>
</tr>
<tr>
<td>CALIPSO (*)</td>
<td>GPM/DPR</td>
</tr>
<tr>
<td>CATS</td>
<td>SCARAB</td>
</tr>
<tr>
<td>CERES</td>
<td>SEVERI</td>
</tr>
<tr>
<td>CLARREO</td>
<td>Sentinel 3 (OLCI+SLSTR)</td>
</tr>
<tr>
<td>MODIS</td>
<td>VIIRS</td>
</tr>
</tbody>
</table>

(*) = several proposals will use CALIPSO even in case there would be no Mission overlap in time. In that case they will use the CALIPSO Dataset in a statistical manner.
4.8 Caveat: for some satellites – few collocations with EarthCARE (example below is Sentinel 3/OLCI – EarthCARE/ATLID)
4.9 Validation Activities for ESA EarthCARE Products: Assessment

The validation contributions have been presented during the 1st ESA EarthCARE Validation Workshop from 13 to 15 June 2018 in Bonn, Germany. The workshop conclusion was that the combination of all proposed contributions will form an adequate validation programme for EarthCARE, with the following areas requiring further attention:

- The sum of all contributions is **needed in full** to avoid gaps. It is imperative that full funding is achieved.

- Better coverage is needed for the Tropical regions.

- The geographical coverage of Lidars is considered good, whereas the coverage of Cloud Profiling Radars could benefit from additional instruments.

- Many of the Cloud Profiling Radars are not equipped with Weather Radars for context. Improving on this would reduce the representativity error.
4.10 EarthCARE Validation Support Functions

- **Correlative Data Repository:** ESA Atmospheric Validation Data Centre (EVDC)
- **EVDC data conversion tools:** Correlative data are to be shared using GEOMs metadata and common templates. Conversion tools are available at the EVDC
- **Tools for data decoding, data analysis, and data intercomparison:** a suite of tools is under development to assist with the following operations:
  - Discover EarthCARE Products
  - Intercompare correlative with EarthCARE data products
  - Subsetting of EarthCARE data products
  - Visualisation of EarthCARE data products
- **EarthCARE Simulator:** Simulates EarthCARE data based on a geophysical scene
- **Service for overpass prediction:** Principal Investigators can request predictions (or calculate themselves using tools on the next slide)
### 4.11 Validation Support Functions: Overpass tools

<table>
<thead>
<tr>
<th>Usage</th>
<th>Desktop</th>
<th>Command Line</th>
<th>Web Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overpass table generation for fixed, ground based sites</td>
<td>ESOV</td>
<td>GroundSitePass</td>
<td>OPOT</td>
</tr>
<tr>
<td>Overpass table generation for Balloon Trajectories</td>
<td>ESOV</td>
<td>BalloonOverPass (still being prototyped)</td>
<td>OPOT</td>
</tr>
<tr>
<td>Identification of overpass geolocations and times inside (airborne) campaign area</td>
<td>ESOV</td>
<td>ZoneOverpass</td>
<td>OPOT</td>
</tr>
<tr>
<td>Identification of overlapping sampling volumes between EarthCARE and another satellite instrument</td>
<td></td>
<td>Instrument Collocation</td>
<td></td>
</tr>
<tr>
<td>High-Image-Quality Orbit Swath Visualisation</td>
<td>SAMI</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.12 Interactive EarthCARE Validation Portal

Objectives of this portal are to:

- Present the EarthCARE validation activities
- **Solicit new contributions**
- support coordination of the ESA EarthCARE Validation Team (ECVT)
- structure the interactions between ECVT scientists, subgroup leaders, instrument experts, algorithm developers, and campaign participants
- provide the latest information on instrument (un)availability, mission planning, instrument/product/algorithm changes

The portal landing page is at [https://earthcare-val.esa.int](https://earthcare-val.esa.int)

Please contact esa-ecvt@earthcare.esa.int if you are interested in participating in the validation of EarthCARE

Teams with accepted proposals are incorporated into the ESA EarthCARE Validation Team, and benefit from early and exclusive access to preliminary EarthCARE data (well before the public release of the consolidated data) and from close interaction with instrument and algorithm experts.
5. EarthCARE Validation Timeline

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESA-JAXA Validation Implementation Plan 1.0</td>
<td>Q2 2020</td>
</tr>
<tr>
<td>Pre-launch ESA-JAXA validation workshop</td>
<td>Q4 2021</td>
</tr>
<tr>
<td>ESA-JAXA Validation Implementation Plan 2.0</td>
<td>Q1 2022</td>
</tr>
<tr>
<td>ESA Validation Rehearsal</td>
<td>Q2 2022</td>
</tr>
<tr>
<td>ESA Validation Rehearsal Review / Readiness Review</td>
<td>Q2 2022</td>
</tr>
<tr>
<td>EarthCARE Launch</td>
<td>June 2022</td>
</tr>
<tr>
<td>ESA-JAXA Preliminary Validation Results Review</td>
<td>January 2023</td>
</tr>
<tr>
<td>EarthCARE Long-term Validation Phase</td>
<td>January 2023 until End-of-Mission</td>
</tr>
</tbody>
</table>
Contact esa-ecvt@earthcare.esa.int and visit the validation portal: